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Bending Characteristics of Open cell Polymer Foam Sandwich Structure

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Abstract

The aim of this article is to investigate the effect of a kind of polymer foam and skin on bending behavior of open cell polymer foam based sandwich structures using three point flexural tests. The flexural test has core shear stress, face sheet bending stress and also beam deflections were considered for studying bending behaviour of the sandwich structure. The results show the polymer-polymer cored-polymer(PPP) sandwich has maximum bending strength compared to other five sandwich structures. Failure mechanisms of the fractures specimen were studied through scanning electron microscopy, which reveals that delamination starts at interface between core and skin of the sandwich structure though initiated at the middle of the polymer core when observed between the tensile and compressive regions. The polymer sandwiches failed predominantly due to face-core de-bonding with a large scatter at a measured peak load and crosshead deflection. The bending data is very useful for designing sandwich beams with lightweight and multifunctional applications.

Keywords: Polymer foams, Sandwich Strectures, Debonding, Bending,Mechanical properties

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1. Introduction

Several types of light weight polymer composites are being developed for use in applications ranging from aerospace structures, marine, construction of building structures, sport industry to automobile components. However, hollow foam composites or syntactic foams have recently gained a lot of attention as they provide the same strength characteristics and much lower density than that of the solid foam. However, several studies have been focused on the fabrication of polymer foam. But, only a few researchers have worked on the performance of low cost open cell polymer foam based sandwich structures. The objective of this research was to fabricate open cell polymer foam, sandwich structure using the same foam and their characterization on bending strength .

By sandwiching a low density core between stiff face sheets effectively provide a lightweight, stiffer and stronger sandwich structure. The face sheets are basically unidirectional fiber- reinforced laminated composites, while the core is a thick layer of low-density material like foam or a honeycomb material[1]The core materials were traditionally manufactured using stochastic metal or polymer foams[2,3], corrugated [4], honeycomb [5,6] and truss materials [7,8]. These combinations of properties are very important in the development of many contemporary vehicles and structures. Sandwich structures generally allow an additional weight reduction without jeopardizing the strength and performance of the structure by using fiber -reinforced composites in it. Hence sandwich structures made of fiber reinforced composites are attractive for buildingultra-light and high-strength components, specially for the aerospace industry and fight structures[9]. Larger-sized, mass-produced sandwich panels have many potential applications in building large-scale structures. In addition they are energy absorbent [10].

The study on bending properties is very important in design of lightweight sandwich beams. There is much literature is available pertaining to bending behavior of sandwich beams with various kinds of cores.Liu et al.(2010) presented a semi-analytical method for the bending analysis of sandwich panels with square honeycomb cores. Jin et al.(2013) conducted bending tests in order to reveal the mechanical property and the failure mechanism of integrated woven corrugated sandwich composites. Zok et al. (2004) reported a protocol for characterizing the bending performance of metal sandwich panels with pyramidal truss cores. Valdevit et al.(2004) presented the optimised results regarding sandwich panels with prismatic cores under bending load. Rathbun et al.(2004) have investigated the bending behaviour of light weight metallic sandwich structures with tetrahedral truss cores.Typically, cores are the weakest part of sandwichstructures and they fail due to shear. Sendlein et al.(1991) reported that understanding theshear strength properties of sandwich core plays an important rolein the design of sandwich structures subjected to flexural loading.Frosting et al. (1990) Therefore, three-point bending tests are often performed tofind the flexural and shear rigidities of sandwich beams . Fan et al. (2007) have reported the bending properties of kagome and improved carbon fiber reinforced lattice-core sandwich beams were investigated. To date, however, there is no research work on the bending behaviour of sandwich beam with open cell polymer foam as core material , since this innovative core architecture appeared recently for designing lightweight and multifunctional sandwich structure. The properties of the parent material are listed in Tabel 1. In the present paper, the bending properties and the failure mechanism of glass fiber composite sandwich beam with open cell polymer foam cores have been researched using experimental tests.the PPP possess as higher value of bending stress compared to five specimens. EEP possess higher value of core stress and sandwich beam deflection compared to other sandwich specimen.

2. Experimental

2.1 Fabrication

The material used for this experiment and their properties are given in Table 1. Polymer open cell core was fabricated by placing water dissolvable balls inside the mould filled with epoxy/polyester resin mixed with accelerator and catalyst and curing for 24 hours. The polymer foam was placed in hot water for 15 minutes. GFRPs using polyester and epoxy resins and glass reinforcement were used as skins for the sandwich structures fabricated by wet hand lay-up technique. Six types of specimens such as EEE (Epoxy/glass front face-Epoxy core- Epoxy/glass back sheet), PPP (polyester/glass front face- polyester core-polyester/glass back sheet), EPE (Epoxy/glass front face-polyester core- Epoxy/glass back sheet), PEP (polyester/glass front face- Epoxy core- polyester/glass back sheet), PEE (polyester/glass front face- Epoxy core- Epoxy/glass back sheet) and PPE (polyester/glass front face-polyester core- Epoxy/glass back sheet).As per calculation, six numbers of fiber mats of area 150 mm x 150mm were prepared for face sheet.18 g of polyester resin /epoxy resin, hardener 2% of accelerator (methyl ethyl ketone peroxide) and 2% of catalyst (diethyl acetamide) for polyester resin and 10% amine based hardener for epoxy resin were used. Resin and hardener were stirred for five minutes for uniform mixing. Mixture of resin-hardener was applied to the Mylar sheet using a spreader on ceramic tile. The glass mats are placed on the Mylar sheet and apply mixture applied on the ply until the entire ply gets uniformly wetted. This procedure continues until to get 1 mm thickness of the face sheet.Finally, the Mylar sheet is covered with the FRP laminates and finally ceramic tile was placed over this Mylar sheet and the specimen was allowed to cure for 24hrs. Placed prepared polyester / epoxy open cell foam on the epoxy / polyester face sheet during preparation.Apply calculated amount of polyester/ epoxy resin (5g) (resin + hardener) mixture resin is spread on a face sheet and foam material using spreader.Then face sheet is placed on a top and bottom of the foam material and covered with two tile blocks for 24 hrs.

Table1. Material used and their properties

Material	Density (g/cm^3)	Volume fraction (%)	E (Gpa)
Epoxy	1.4	0.35	3
E-glass fibre (0/90)	2	0.65	2.5
Polyester	1.2	0.35	2.8

2.2 Three point bending tests

In this section, we performed three point bending tests on sandwich specimens with different cores.Three point bending test method according to ASTM C 393-00 was used to measure the core shear stress and facing bending stress of the composite sandwich panels. For this purpose, three point bending test specimens with six different combinations of face sheet and core. The composite sandwich dimensions were130mm X 32mm X 12mm and tests were performed using the mechanical test machine at a crosshead speed of 1mm/min. Each specimen was tested and force versus stroke values was recorded using Universal test machine [11].The applied load was recorded by an INSTRON 5569 testing machine during bending tests. Core shear stress (τ) values were determined by the equation .1

$$\tau = \frac{p}{(d+c)b} \qquad (1)$$

Where P is load, d is sandwich thickness, c is the core thickness and b is the sandwich width. Face sheet bending stress (σ) is obtained by the equation.2.

$$\sigma = \frac{PL}{2t(d+c)b} \qquad (2)$$

Where t is face sheet thickness and L is the span length. The dimensions mentioned above can be seen in Figure 1

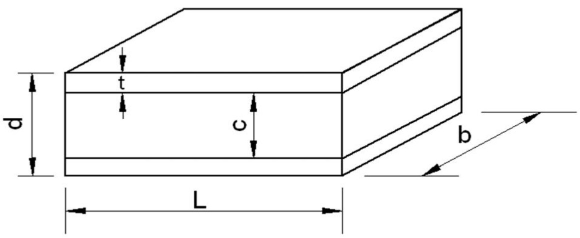

Fig. 1.Sandwich structure dimensions

Panel bending stiffness (*D*) is obtained by the formula given equation.3

$$D = \frac{E\left(d^3 - c^3\right)b}{12} \tag{3}$$

E is the face sheet modulus.
Sandwich beam deflection is also calculated in this test method by equation 4.

$$\Delta = \frac{PL^3}{48D} + \frac{PL}{4u} \tag{4}$$

Δ is the total beam mid span deflection. In this formula *U* is the panel bending rigidity and it is calculated by the equation .5.

$$U = \frac{G(d+c)^2 b}{4c} \tag{5}$$

G is the core shear modulus.

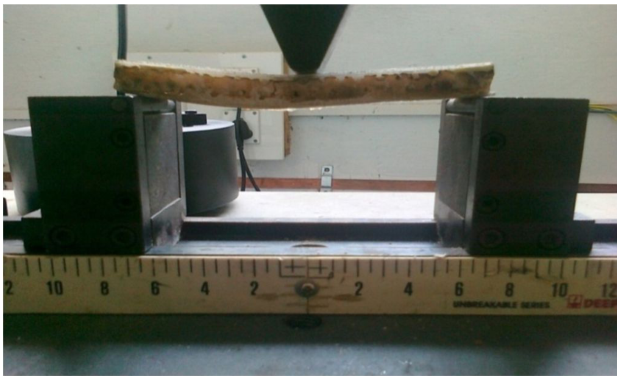

Fig. 2.Three-point bending test on sandwich specimen

3. Results and Discussion

Three-point loading tests experiments are carried out according to ASTM C 393-00. The machine was programmed to apply the load at a constant crosshead rate. Choose the test span length (120 ± 0, 1) mm.By applying bending load on the rectangular specimen of size 130 x 32 mm^2 in the mid span of the sandwich panels.The bending load was applied at a cross head speed of 1mm/min.The loading was stopped when test piece cracked. The calculation of shear stress and bending movement were calculated as per standard formulae.

Three point bending test was applied to the sandwich structures in order to evaluate the core shear stress, face sheet bending stress and sandwich beam deflection variation in accordance with the deflection. Figure.3 shows EEE sandwich specimen core shear stresses at the peak load and sandwich beam deflection decrease after the peak load. Sandwich structure face sheet bending stress as a function of the deflection is given. Figure 4.shows EEP sandwich specimen core shear stresses at the peak load and sandwich beam deflection decrease after the peak load. Sandwich structure face sheet bending stress as a function of the deflection is given. Figure 5 show PEP sandwich specimen core shear stresses at the peak load and sandwich beam deflection decrease after the peak load. Sandwich structure face sheet bending stress as a function of the deflection is give. Figure 6shows PPP sandwich specimen core shear stresses at the peak load and sandwich beam deflection decrease after the peak load. Sandwich structure face sheet bending stress as a function of the deflection is given. Figure7shows EPE sandwich specimen core shear stresses at the peak load and sandwich beam deflection decrease after the peak load. Sandwich structure face sheet bending stress as a function of the deflection is given. Figure8 shows EPP sandwich specimen core shear stresses at the peak load and sandwich beam deflection decrease after the peak load. Sandwich structure face sheet bending stress as a function of the deflection is given. .Stress values increase linearly in the elastic region.Maximum stress was applied at the mid span in three point bending configuration. Above the maximum stress, the composite layers delaminate and failure occurs. The loading in the bending test consists of compression forces. The delamination starts at the middle of the specimen because of the maximum bending moment in the middle section, of the tensile surface fiber rupture occurred.

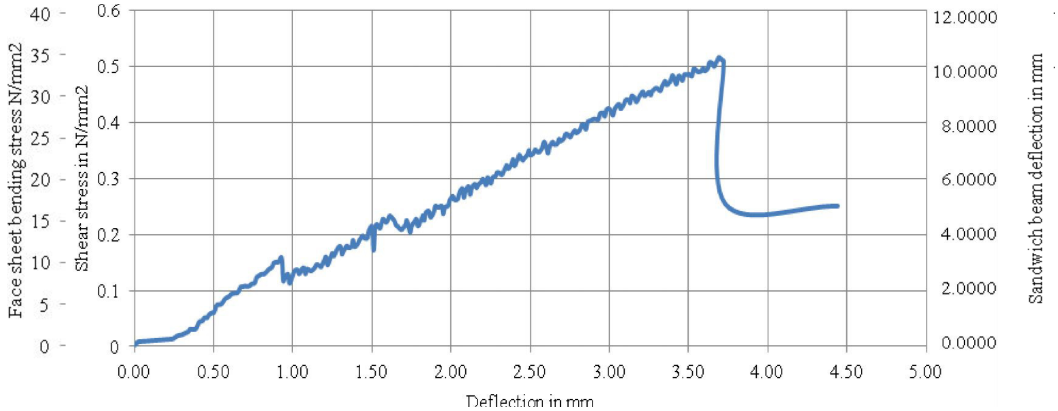

Fig. 3. Face sheet bending, shear stress, and Sandwich beam deflection as a function of deflection of epoxy foam based sandwich specimen for EEE specimen

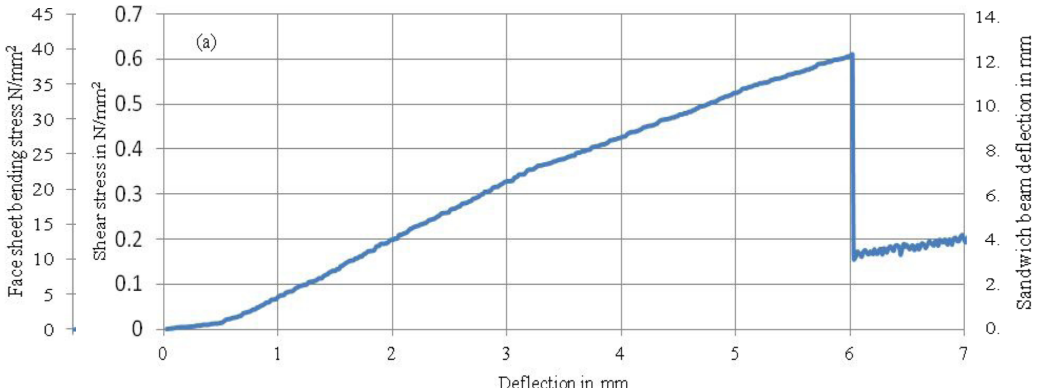

Fig. 4. Face sheet bending, shear stress, and Sandwich beam deflection as a function of deflection of epoxy foam based sandwich specimen for EEP specimen

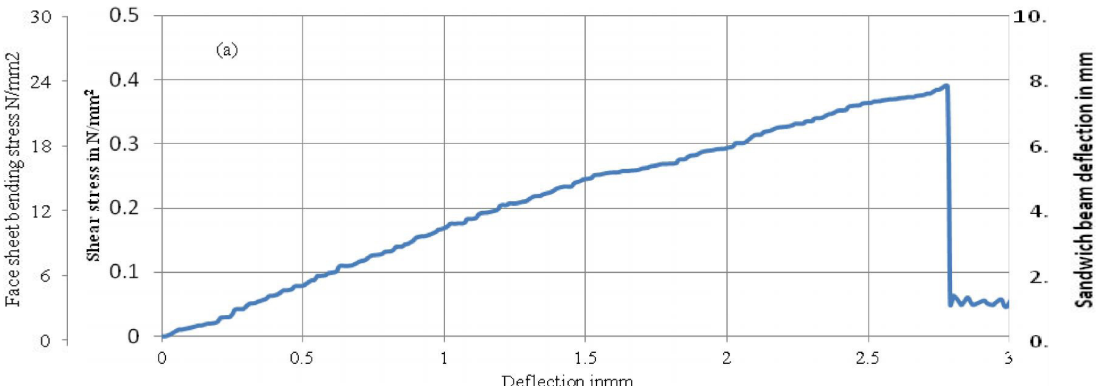

Fig. 5. Face sheet bending, shear stress, and Sandwich beam deflection as a function of deflection of epoxy foam based sandwich specimen for PEP specimen

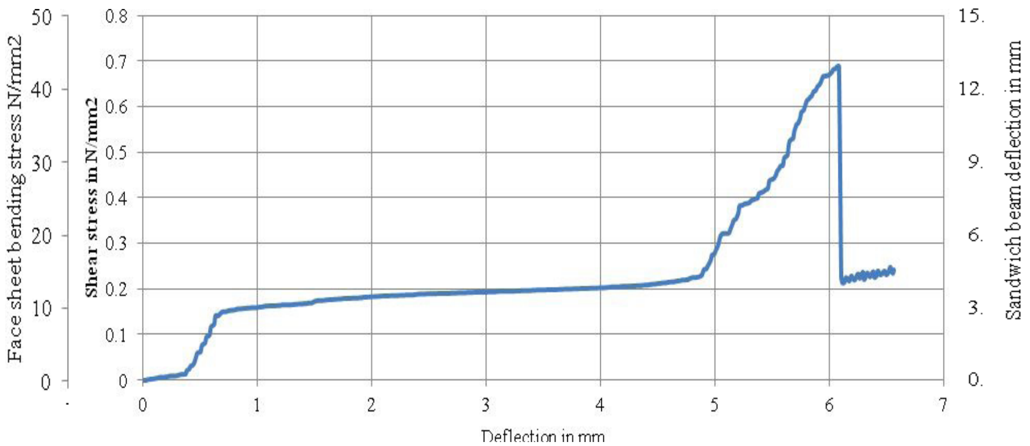

Fig. 6. Face sheet bending, shear stress, and Sandwich beam deflection as a function of deflection of epoxy foam based sandwich specimen for PPP specimen

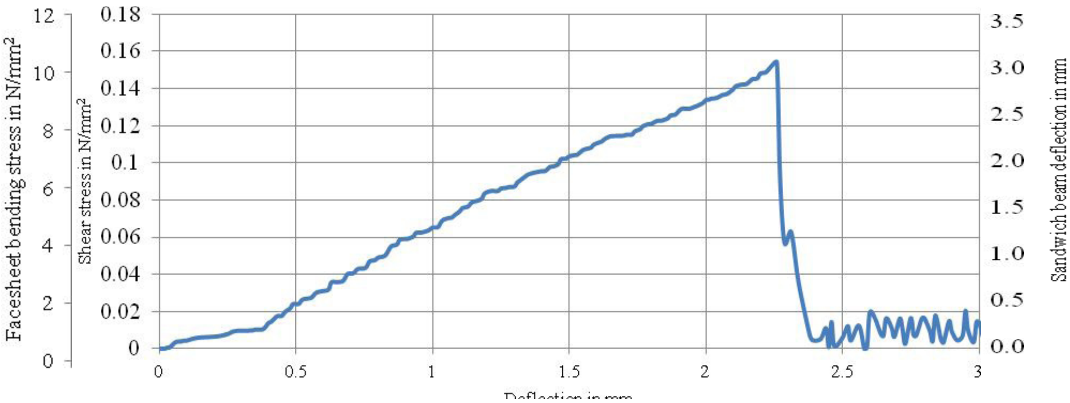

Fig. 7. Face sheet bending, shear stress, and Sandwich beam deflection as a function of deflection of epoxy foam based sandwich specimen for EPE specimen

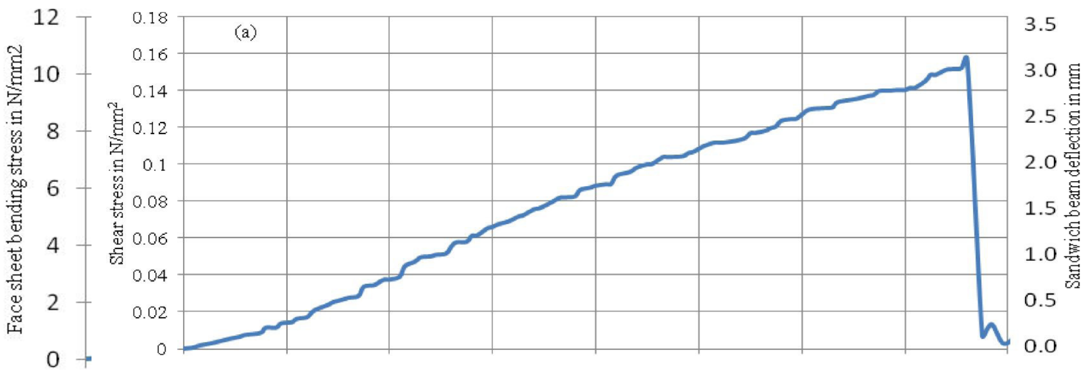

Fig. 8. Face sheet bending, shear stress, and Sandwich beam deflection as a function of deflection of epoxy foam based sandwich specimen for EPP specimen

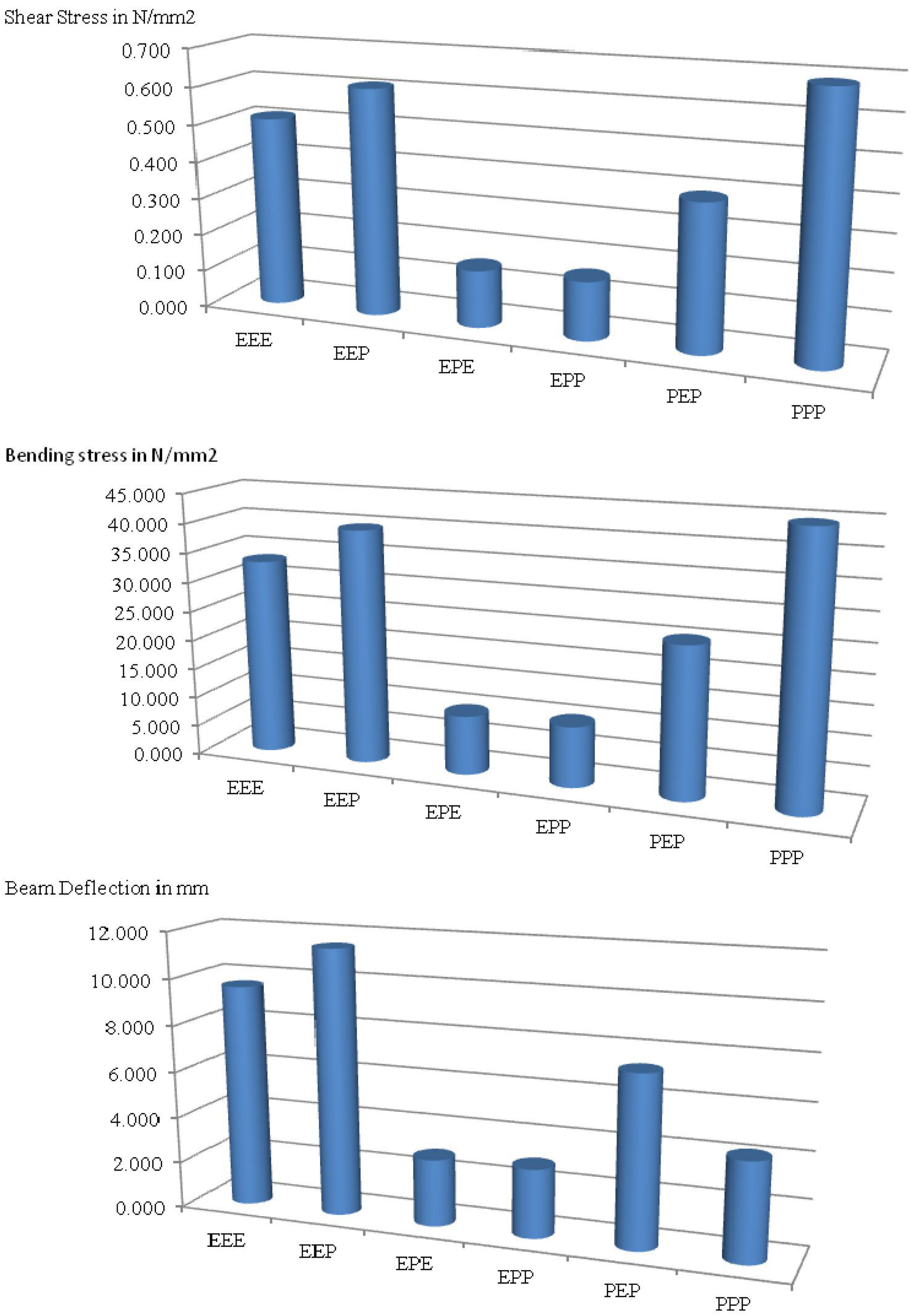

Fig.9. Shear stress, Face sheet bending and Sandwich beam deflection Peak load / Type of material polyester and epoxy foam based sandwich specimen.

Delamination was observed on both tensile and compressive surfaces of the specimen's fiber failure, large deflection was achieved. The stress-deflection curve has a linear portion at the beginning. On the opposite side, that is, under tension; the core remained perfectly bonded to the face sheet. The polymer sandwiches failed predominantly due to face-core de-bonding with a large scatter in measured peak load and crosshead deflection at failure. They also showed very limited nonlinearity in stress-deflection response. The nonlinearity in this architecture is primarily due to face sheet yielding as well as de-bonding between the phases of the interpenetrating composite foam cor+e. [11] From Figure 9.it is inferred that, the PPP possess as higher value of bending stress compared to five specimens. The bending stress of sandwich structure is 21.33 N, 34.1 N, 22.06 N, 5.5 N, and 12.25 N more than PEP, EPP, EPE, EEP, and EEE respectively. EEP possess higher value of core stress and sandwich beam deflection compared to other sandwich specimen.

4. Conclusions

Glass fiber composite sandwich structures with open-cell polymer foam cores have been fabricated as per the ASTM standard using e-glass fiber / epoxy face sheet / e-glass/ polyester faces with epoxy / polyester based core. Three point bending tests were carried out to study the mechanical behaviours of the composite sandwich beam with open-cell polymer foam cores. The bending behaviour continuously increased with increasing bending deflection, reached peak then it fails in the form of a fracture. The six sandwich structures show different bending stresses and shear stresses. The PPP shows maximum bending stress and EPE shows lowest bending stress. The sandwich deflection causes due to polymer foam crushing and the crack initiated between the foam. The little debonding can be seen between skin and foam.

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